

Geopositional Accuracy Validation of Orthorectified Landsat ETM+ Imagery

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March 15, 2004

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Scope of Work

This report provides the results of two independent evaluations, an absolute and a relative assessment, of the geopositional accuracy of the Earth Satellite (EarthSat) Corporation's GeoCover™ orthorectified Landsat Enhanced Thematic Mapper Plus (ETM+) imagery. This imagery was purchased through NASA's Earth Science Enterprise (ESE) Scientific Data Purchase (SDP) program via NASA contract NAS13-02032.

Background

One of the techniques used to validate the geopositional accuracy of EarthSat's ETM+ imagery required the use of validated Landsat Thematic Mapper (TM) imagery. The TM imagery used in this assessment was purchased from EarthSat through the SDP via NASA contract NAS13-98046. The geopositional accuracy of this TM imagery was independently validated by Earth Science Applications (ESA) Directorate personnel prior to this effort.

The TM sensor onboard Landsat 4 and Landsat 5 is a high-spatial-resolution (30-meter ground sample distance (GSD)), multispectral system with seven bands in the visible and infrared (IR) regions of the electromagnetic spectrum. EarthSat employed a two-step process to orthorectify the TM imagery. The first step orthorectified TM scenes for which government-provided ground control points (GCPs) were available. The second step used the initially orthorectified scenes as control to tie the remaining raw imagery together using a single block adjustment. These orthorectified regions correspond to general land areas, or blocks, throughout the world. The result of this process is the block-orthorectified set of Landsat TM imagery that was delivered to NASA through the SDP. The SDP contract specification for horizontal geopositional accuracy of the TM dataset is a net root mean square error ($RMSE_{net}$) of 50 meters.

SSC ESA Directorate personnel then independently validated the orthorectified TM imagery for horizontal geometric accuracy. Additional validation-dedicated, government-provided ground control data was used to this end (i.e., the validation-dedicated GCPs were separate and independent of the GCPs used in the EarthSat orthorectification process). However, because of the limited number of additional government-provided GCPs within each scene, the validation assessment was performed by geographic block as opposed to individual scenes. Table 1 presents the results of the TM geolocational accuracy assessment including the x-component of the root mean square error ($RMSE_x$), the y-component of the root mean square error ($RMSE_y$), and the $RMSE_{net}$. Additional background and test procedures used in the TM validation effort may be found in the publicly available TM validation reports located on the ESA Web site at http://www.esa.ssc.nasa.gov/datapurchase/v_v/es/es_val_reports.asp.

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Table 1. TM Validation Results

TM Block	$RMSE_x$ (meters)	$RMSE_y$ (meters)	$RMSE_{net}$ (meters)	Number of GCPs Available	Number of GCPs Utilized
Alaska	30.57	33.40	45.28	61	43
Balkans	23.17	21.53	31.62	78	49
Caribbean	19.17	19.87	27.61	67	53
Central America	19.44	15.32	24.75	12	6
Central Asia	18.45	27.53	33.14	27	18
Central North America	19.33	18.56	26.80	57	47
East Africa	20.88	18.97	28.21	149	135
Eastern North America	18.66	18.90	26.56	62	50
Europe	24.46	26.64	36.16	140	96
Middle East	32.84	29.12	43.89	89	56
North Africa	28.95	38.28	48.00	6	6
Northeast Asia	24.42	25.61	35.39	80	49
Northern South America	17.57	39.36	43.11	92	73
Northwest Asia	35.81	27.39	45.09	12	10
South Africa	17.86	19.22	26.24	82	50
Southeast Asia	24.38	26.45	35.97	130	90
Southern South America	1.58	2.40	2.87	9	9
Western North America	16.08	14.45	21.6	73	55

NOTE: Highlighted data denotes blocks where fewer than 20 ground control points were available for statistical analysis.

The ETM+ sensor onboard Landsat 7 is also a high-spatial-resolution (30-meter GSD) system with seven multispectral bands spanning the visible through IR spectral regions and an additional panchromatic band. The ETM+ imagery used in this assessment was also orthorectified by EarthSat.

EarthSat employed a two-step process for ETM+ imagery orthorectification that is very similar to the TM orthorectification process. The first step exploited the TM scenes that had previously been orthorectified using government-provided GCPs as ground control for a relative (thin-plate spline) orthorectification of the corresponding ETM+ image. In the second step, the remaining raw ETM+ imagery was tied together using a block adjustment to yield near-world coverage of orthorectified ETM+ imagery. Exceptions to this orthorectification process were ETM+ geographic blocks identified as “Greenland,” “Indonesia,” “Islands,” “Upper South America,” and “Siberia.” In these cases, the horizontal control was provided for these regions through the ETM+ definitive ephemeris.

SSC remote sensing personnel validated the orthorectified ETM+ imagery for horizontal geometric accuracy by performing both relative and absolute accuracy assessments. The relative accuracy assessment refers to the computation, examination, and analysis of statistical data representative of the relationship that exists between the ETM+ orthorectified imagery and the corresponding TM orthorectified imagery. Distinguishable geographic landmarks that were identified within both sets of imagery were used to perform this validation activity. The absolute accuracy assessment refers to the

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computation, examination, and analysis of the statistical data representative of the relationship between ETM+ orthorectified imagery and government-provided GCPs.

Geodetic Control Reference Data

Two separate and independent sets of government-provided GCPs are key to the orthorectification and validation processes. One of these sets of GCPs was delivered to EarthSat for use in the orthorectification of Landsat TM data. The second, independent set of GCPs was delivered to the ESE SDP program for use in the validation of Landsat TM and ETM+ geopositional accuracy. The control information was available in the form of both hardcopy documentation and softcopy computer files that duplicated the hardcopy coordinate documentation. The softcopy version enabled control point reference data to be imported into image processing software with minimal opportunities for error. The hardcopy documentation included pencil drawings of the terrain surrounding the geographic landmarks depicted by the GCPs. This data was essential to the Landsat TM geopositional accuracy assessment and to the Landsat ETM+ geopositional accuracy assessment.

Approach

To understand the ETM+ validation approach, it is useful to define the ETM+ horizontal accuracy specifications. The geometric accuracy specified for Landsat ETM+ is defined both in terms of relative accuracy to TM imagery and of absolute accuracy to ground coordinates. The relative geolocal accuracy specification for orthorectified ETM+ imagery procured through the SDP is an $RMSE_{net}$ of ± 40 meters. Similarly, the absolute geolocal accuracy specification for Landsat orthorectified ETM+ imagery procured through the SDP is an $RMSE_{net}$ of ± 64 meters. Both of these specifications are stipulated in NASA contract NAS13-02032 with EarthSat. If the $RMSE_{net}$ values exceeded ± 40 meters for the relative assessment or ± 64 meters for the absolute assessment, then the data was analyzed on a scene-by-scene basis to attempt to locate points that may have been erroneously biased because of incorrect analyst interpretation. When specific points were identified as having exceptionally large geolocal errors, the scenes were re-examined near the area in question. If the imagery was determined to be flawed, then the scene or scenes would be discussed with EarthSat for discrepancy resolution.

To verify the relative geometric accuracy of the ETM+ imagery, selected ETM+ scenes were compared to the corresponding verified/validated TM scenes. The locations of identifiable features in ETM+ scenes were compared to the locations of the same features within the TM scenes. For each ETM+ scene, a population of 10 or more identifiable geographic landmarks were located and recorded in both the TM and the ETM+ scenes. The resulting array of Universal Transverse Mercator (UTM) coordinates constituted the relative assessment dataset for the selected ETM+ scene. The datasets for each scene were then compiled into a block dataset, and the statistics calculated from the data in this block dataset were compared to the relative geometric specifications for orthorectified ETM+ data.

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To verify the absolute accuracy of the ETM+ imagery, selected scenes were evaluated using the aforementioned government-provided GCPs. When possible, the geographic landmarks in the ETM+ imagery that corresponded to the GCP hardcopy drawings were located. This process resulted in a dataset containing the imagery UTM coordinates and the corresponding government-provided reference UTM coordinates. As before, the arrays for each scene were then compiled into a block dataset, and the statistics calculated from the data in this block dataset were compared to the absolute geometric specifications for orthorectified ETM+ data.

Dataset

Two limiting factors determined the size of the datasets that were used for the ETM+ relative accuracy and absolute accuracy assessments. The first, most limiting factor was the small number of ETM+ images, compared to global coverage, that could be used for this exercise. The small number of validation scenes is directly related to the small number of government-provided GCP data packets that provided the validation truth data for the TM geolocational accuracy assessment and for the ETM+ absolute accuracy assessment. An illustration of the global distribution of validation scenes is available in Appendix A. The second limiting factor was the number of definitive monuments (GCPs in the absolute assessment and geographic landmarks in the relative assessment) per scene that could be selected to perform the necessary computations and analyses. A set of 100 images was used for both the ETM+ relative accuracy assessment and the ETM+ absolute accuracy assessment.

Procedure

The relative horizontal geometric accuracy assessment of ETM+ imagery began with the identification of images that corresponded to previously validated TM images. Next, the data was analyzed using the GCP editor function available in ERDAS IMAGINE image processing software. For each scene, the Landsat ETM+ and corresponding TM images were loaded into separate viewers. Once loaded, both the ETM+ and the TM images were inspected for clearly identifiable features. When specific landmarks, such as rock formations, roads, and waterways, were identifiable in both scenes, these landmarks were selected and geographically located. This action populated the X-Input and Y-Input fields in the software's GCP editor. For each ETM+ scene, a population of 10 or more identifiable geographic landmarks were located and recorded in both the TM and the ETM+ scenes. The resulting array of UTM coordinates constituted the relative assessment dataset for the selected ETM+ scenes.

The ETM+ absolute horizontal geometric accuracy assessment began with the identification of images that corresponded to the government-provided GCP packets. This assessment was also performed using the GCP editor function available in ERDAS IMAGINE. For each scene, the same ETM+ image was opened in both viewers. Once opened, the government-provided GCPs were imported into the GCP editor function as reference points. This populated one of the viewers with crosshairs denoting the locations of the provided GCPs. At this point, the monuments called out in the GCP hardcopy data

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packets were located in the viewer that was not displaying the government-provided GCPs. Once located, the monuments were selected, populating the GCP editor function as input points. The resulting array of UTM coordinates constituted the absolute assessment dataset for the selected ETM+ scene. Typically all points associated with this data were not located. The most common reason for inability to locate the GCPs was that the control locations were not within the confines of the scene being examined. Other reasons for not locating GCP landmarks included terrain uniformity and land change.

In both the ETM+ relative and absolute accuracy assessments, the individual scene datasets were exported and compiled into larger datasets corresponding to the geographic block in which the imagery was originally orthorectified. These larger datasets contained the point IDs, input coordinates, and reference coordinates for each scene and provided the required input into the ESA Directorate's Visual Basic program written to compute relative geopositional accuracy. For each point, the Visual Basic program computed the X-differences and Y-differences, the squares of the X-differences and Y-differences, the $RMSE_x$ and $RMSE_y$, and the $RMSE_{net}$ using the following accuracy formulas:

$$RMSE_x = \sqrt{\frac{\sum (X_{input} - X_{control})^2}{n}}$$
$$RMSE_y = \sqrt{\frac{\sum (Y_{input} - Y_{control})^2}{n}}$$
$$RMSE_{net} = \sqrt{(RMSE_x)^2 + (RMSE_y)^2}$$

where X_{input} , Y_{input} are the coordinates of the ETM+ input points; $X_{control}$, $Y_{control}$ are the coordinates of the TM reference points; and n is the total number of usable points.

Results

The relative assessment used all 100 ETM+ scenes located throughout the world. From these scenes, 1065 geographic landmarks were used for analysis. All 18 blocks passed the 40-meter $RMSE_{net}$ relative geographic accuracy specification. The statistics calculated on the ETM+ relative assessment are presented in Table 2. The maximum $RMSE_{net}$ found for the relative assessment was 34.90 meters, the minimum $RMSE_{net}$ found for the relative assessment was 13.89 meters, and the average $RMSE_{net}$ found for the relative assessment was 25.84 meters.

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Table 2. ETM+ Relative Horizontal Geometric Accuracy Calculations

ETM+ Geographic Block	$RMSE_x$ (meters)	$RMSE_y$ (meters)	$RMSE_{net}$ (meters)	Number of Point Pairs
Africa – World Summit on Sustainable Development	23.29	25.15	34.28	30
Caribbean	15.61	19.37	24.88	30
Europe	20.50	18.15	27.38	70
Europe 2	17.95	17.67	25.19	60
Indonesia	23.63	25.38	34.68	25
Lower North America	16.97	17.35	24.26	140
Lower South America	26.21	18.73	32.22	20
NE Africa	17.19	19.40	25.92	100
NE Asia	16.46	14.87	22.18	40
NW Africa	22.12	27.00	34.90	20
NW Asia	12.68	13.51	18.53	30
SE Asia	25.62	18.78	31.76	130
South Africa	14.04	14.27	20.02	80
SW Asia	20.60	20.99	29.41	50
SW Asia 2	14.41	14.78	20.64	30
Upper North America 2	10.14	9.49	13.89	20
Upper North America 3 (Alaska)	18.10	19.70	26.76	110
Upper South America	12.84	12.88	18.19	80

The absolute assessment also used all 100 ETM+ scenes located throughout the world. From these scenes, 750 government-provided control points were used in the analysis. Table 3 presents the results of the ETM+ absolute geometric assessment. Note that the geographic blocks identified as “Africa – World Summit on Sustainable Development,” “Indonesia,” “Lower South America,” “Northwest Africa,” and “Upper North America 2” contained fewer than the 20 points suggested by the Federal Geographic Data Committee (FGDC) for statistical analysis. The statistics for these four blocks were nonetheless calculated and included in Table 3. All 18 of the blocks passed the 64-meter $RMSE_{net}$ absolute accuracy specification. The maximum $RMSE_{net}$ found for the absolute assessment was 51.92 meters, the minimum $RMSE_{net}$ found for the absolute assessment was 22.98 meters, and the average $RMSE_{net}$ found for the absolute assessment was 34.88 meters.

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Table 3. ETM+ Absolute Horizontal Geometric Accuracy Calculations

ETM+ Geographic Block	$RMSE_x$ (meters)	$RMSE_y$ (meters)	$RMSE_{net}$ (meters)	Number of GCPs Used
Africa – World Summit on Sustainable Development	43.37	28.54	51.92	10
Caribbean	17.39	27.26	32.33	35
Europe	20.04	24.99	32.04	42
Europe 2	18.88	25.05	31.37	39
Indonesia	21.63	20.60	29.87	17
Lower North America	23.08	24.23	33.46	96
Lower South America	13.17	19.20	23.29	8
NE Africa	15.65	16.83	22.98	60
NE Asia	17.43	23.12	28.95	25
NW Africa	17.87	35.17	39.45	3
NW Asia	22.52	23.23	32.36	20
SE Asia	23.42	24.28	33.73	119
South Africa	18.55	24.30	30.57	78
SW Asia	30.76	34.62	46.31	57
SW Asia 2	26.75	37.81	46.31	30
Upper North America 2	15.73	23.22	28.04	7
Upper North America 3 (Alaska)	18.80	28.70	34.31	45
Upper South America	34.37	37.04	50.53	59

NOTE: Highlighted data denotes blocks where fewer than 20 ground control points were available for statistical analysis.

Limitations

Because the validated Landsat TM imagery was treated as a “truth” dataset for the relative accuracy assessment of the ETM+ imagery, any errors that might exist in the validated TM imagery could potentially have adverse effects on the relative accuracy assessment of the ETM+ imagery.

The ETM+ geolocational accuracy assessment approach was dependent on the geographic distribution of the available government-provided GCPs used in these assessments. This scene distribution is shown in Appendix A.

Inconsistencies could arise during the absolute accuracy assessment as a result of differences in the interpretations of the government-provided GCP drawings and imagery. The hand-drawn target area descriptions also reflect subjectivity; they are based on the perception of the artist, which may differ more or less from that of the analyst.

Finally, the possibility exists for an inherent bias specific to the analyst as a result of the variability in image interpretation skills. The final selection of points also reflects analyst subjectivity.

Appendix A

Validated Landsat ETM+ Scene Locations



